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CORRECTION FOR GRAVITY IN ISOKINETIC DYNAMOMETRY OF KNEE EXTENSORS IN BELOW KNEE AMPUTEES

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ABSTRACT. In isokinetic dynamometry of the knee extensors the influence of gravity on the lower limb is often neglected. The aim of this study was to assess the shape, the quantity and reproducibility of the gravity correction curve (GCC). Eight amputees participated in this study. The GCC was produced on an isokinetic dynamometer (QD) throughout the range of motion on the amputated side with prosthesis and on the non-amputated side. The results were compared with the GCC calculated according to the Cybex data reduction computer procedure. The isokinetic torque registration of the QD is, in a mathematical way, a straight line (Pearson correlation coefficient >0.99). The other GCC is shaped like a cosinus curve. The intra-individual reproducibility is high, the inter-individual variability substantial. An explanation for the difference between the two methods is discussed. For an ideal measurement of the muscular torque, one should not only correct for the effect of gravity but for all factors counteracting the effect of the knee extensors. In that case an individual GCC should be made directly with the dynamometer.

Key words: **isokinetic dynamometer, gravitation error, below knee amputees.**

An isokinetic dynamometer can measure torque produced by a certain muscle group at a preset angular velocity and range of motion. In isokinetic dynamometry of the knee extensors the influence of gravity on the lower limb is often neglected, which results in a relative underestimation of the strength of the knee extensors. Under conditions that result in small torque recordings, the error will be substantial. It is important to measure the effect of gravity through the whole range of motion. A few studies have shown the quantitative consequences for the isokinetic torque curve without correction for gravity (4, 5, 7). The Cybex Data Reduction Computer (CDRC), which provides the data from the Cybex II Plus dynamometer, indirectly calculates the correlation of the torque registration at every joint position (1).

It is also possible, using a dynamometer which allows torque measurement during passive movement, to measure the effect of gravity directly, instead of calculating this effect mathematically. A torque curve can be obtained by measuring isokinetic torque during a passive movement from flexion to extension. The knee extensors and flexors must be fully relaxed. The dynamometer controls, by its own driving and velocity control system, the movement of the leverarm and lower limb. The passive isokinetic torque curve represents gravity throughout the range of motion and may be used to correct active isokinetic torque measurements. This passive torque curve will be called the gravity correction curve (GCC).

The aim of this study was to assess the shape, the quantity and reproducibility of the GCC and to compare them with the GCC calculated according to the CDRC procedure.

MATERIAL AND METHODS

Eight below knee amputees participated in this study. Before actual testing age and sex were recorded. Body mass, mass of the prosthesis with shoe and length of the stump (distance between medial knee joint and end of the tibia) was measured. The mass of the lower leg is, based on body segments, about 6.5% of the total body mass (2, 3). The subjects were tested on an isokinetic dynamometer at the amputated side with prosthesis and at the non-amputated side. The GCCs were determined in two different ways:

Quadriceps dynamometer (QD)

An isokinetic quadriceps dynamometer designed by the Department of Rehabilitation Medicine and the Central Research Workshop of the Erasmus University of Rotterdam, the QD, was used. Contrary to the Cybex II Plus the QD allows for passive torque measurements of the knee extensors from flexion to extension by its own driving system. For further technical details of the QD we refer to the technical note (6). The back rest of the chair and the axis of the lever arm were adjusted in such a way that a rotational alignment of the axis of the knee joint and the axis of the lever arm was achieved. The upper legs were strapped to the chair by a 5 cm broad safety belt. The ankle was fixed to the distal leverarm by a velcro strap. The subjects were requested to relax the leg muscles as

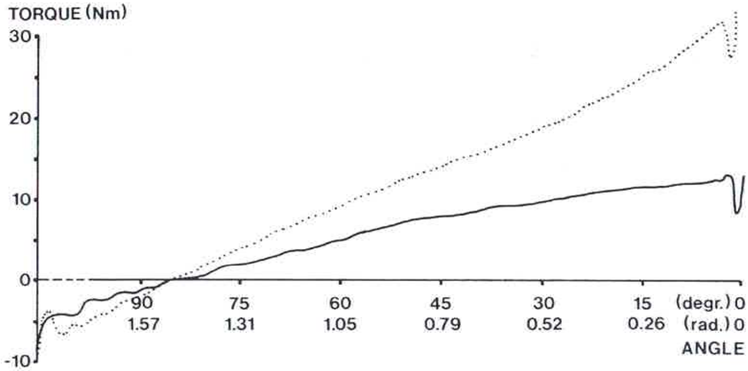

Fig. 1. Typical example of a gravity correction curve on the *X-Y* recorder of the isokinetic dynamometer at an angle velocity of 0.52 rad · s (30 degrees · s). —, amputated leg with prosthesis; . . ., non-amputated leg.

much as possible. Five passive measurements were performed at an angular velocity of 0.52 rads^{-1} (30 degrees^{-1}). In the range from 0 to 1.83 rad (0 rad = max. extension; 6.28 rad = 360° degrees). The GCC was registrated on an *X-Y* recorder. For statistical analysis torque at certain angles in the range of motion (0.26, 0.52, 0.79, 1.05, 1.31 and 1.57 rad) was assessed by reading the five repeated GCC registrations. The mean and standard deviation were calculated. Subsequently regression lines and Pearson correlation coefficients of these data were calculated.

Cybex Data Reduction Computer (CDRC)

In order to correct gravity the Cybex II Plus uses a procedure in which the lower limb is moved passively from 0 to 1.57 rad with an angular velocity of 0.21 rads^{-1} (1). At an arbitrary angle, for example 0.79 rad, torque is determined. A mathematical formula is then used to calculate torque at full extension:

$$M = \frac{M \text{ at } 0.79 \text{ rad}}{\cos 0.79 \text{ rad}}$$

where *M* is torque in *Nm*
The complete GCC is constructed by:

$$M* = M \cdot \cos*$$

where * is angle of the knee.

RESULTS

Age, sex and anthropometric data of the subjects are presented in Table I. A typical example of the *X-Y* registration of the GCC at the QD at 0.52 rads^{-1} of one subject is shown in Fig. 1. In Fig. 2. the means and standard deviations of the 5 repeated measurements of this subject, the regression lines through these data and the GCC according to the CDRC method are shown.

The regression lines through the data of all the subjects at the amputated side and the non-amputated side are presented in Fig. 3. The Pearson correlation coefficient of all these regression lines was at least 0.99. This indicates that in a mathematical way the GCC measured with the QD is a straight line. Those readers who would like to have

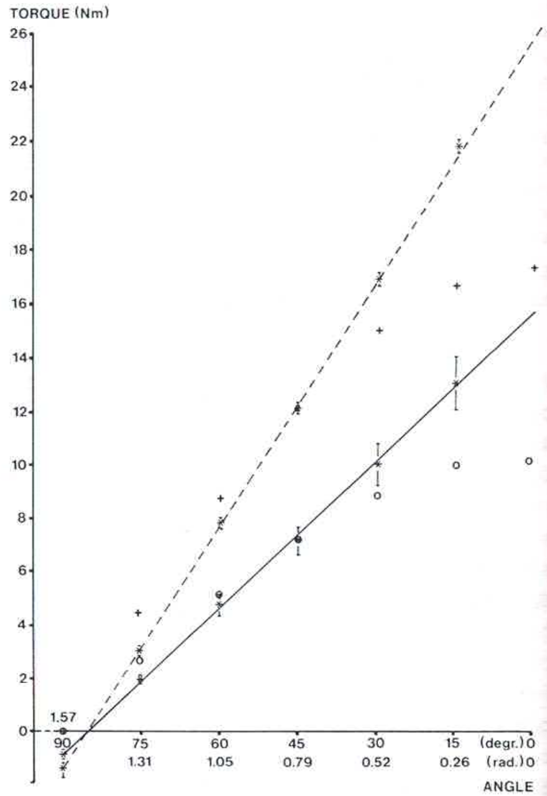

Fig. 2. Gravity correction curve of one person. At the amputated side with prosthesis: ×—×, on the QD determined data and standard deviation; O—O, according to the CDRC calculation, measured angle 0.79 rad. At the non-amputated side: ×- - -×, on the QD determined data and standard deviation; +—+, according to the CDRC calculation, measured angle 0.79 rad.

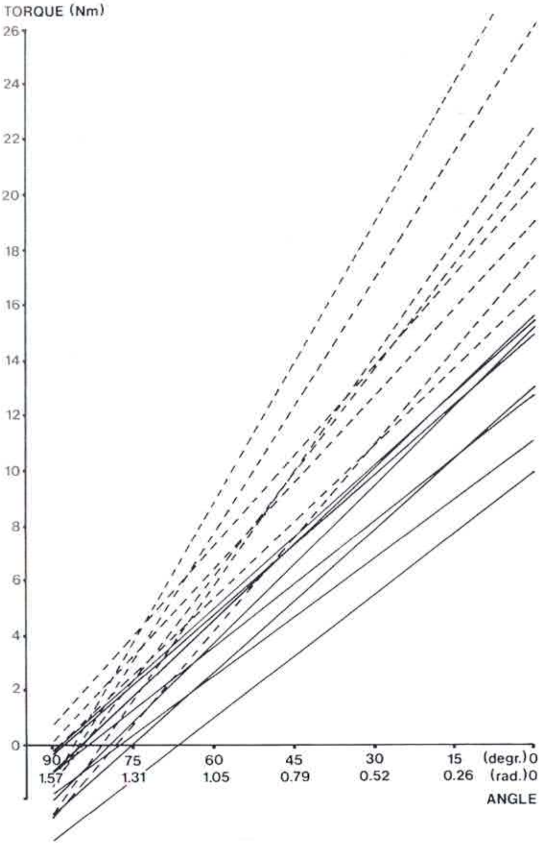

Fig. 3. Regression lines through the data of all the subjects: —, amputated side; – – –, non-amputated side.

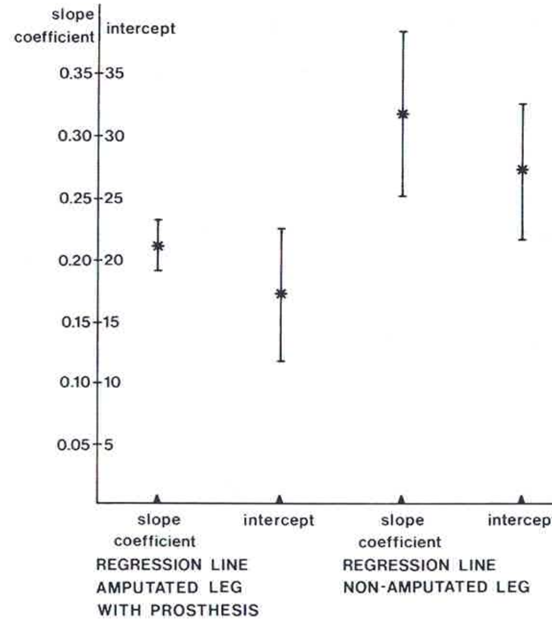

Fig. 4. Average slope coefficient and intercept with the standard deviation of the regression lines through the data of all the values.

detailed data of all the subjects, the parameters of the regression lines and the Pearson correlation coefficients can request these from the authors.

A considerable difference between the GCC measured with the QD and the GCC mathematically constructed on the basis of a cosinus curve (CDRC method) exists. The interindividual variability of these regression lines (expressed by the standard deviation of their intercept and slope coefficients) is presented in Fig. 4.

DISCUSSION

When isokinetic torque is recorded with a dynamometer under passive conditions (i.e. with the knee flexors and extensors relaxed) the torque curve represents mainly the effect of gravity on the lower limb. According to the laws of physics the curve has to be shaped like a cosinus curve if only gravity plays a role.

Table I. *Below knee amputees, anthropometric data*

	1	2	3	4	5	6	7	8	Mean	SD
Age (year)	18	61	51	21	22	67	62	70	46.5	22.4
Sex	M	M	M	M	F	F	M	M	7 M	2 F
Body mass (kg)	66.5	58.5	77.0	69.5	66.0	81.0	67.0	83.5	71.1	8.6
Mass prosthesis (kg)	1.46	1.25	1.70	1.70	1.35	1.75	1.80	1.90	1.61	0.23
Mass lower leg (kg)	4.32	3.80	5.01	4.52	4.29	5.27	4.36	5.43	5.63	0.56
Length stump (m)	13.5	14.5	10.0	13.5	14	12.0	12.0	13.1	12.8	1.4

The GCC of the Cybex II Plus (method 2) is mathematically extrapolated from a torque measurement at 0.79 rad. The shape of this curve is similar to a cosinus curve. However, when the GCC is measured directly with the QD a straight line is found as well at the amputated side with prosthesis as at the non-amputated side. The very high Pearson correlation coefficients of the regression lines are a mathematical proof that the GCC of the QD really is a straight line. From this observation it is concluded that the knee extensors are counteracted not only by gravity but also by other forces. For example a superposition of passive pull of the hamstring muscles when almost full extension is reached. The subject is seated with the hip flexed and most untrained subjects have trouble with full extension in that position. Other factors may be a change in the alignment of the knee axis when the knee moves from flexion to extension, friction in the knee joint and the change of the periarticular soft tissue tension during movement.

For an ideal measurement of the muscular torque, all factors, gravity and biochemical factors, counteracting the knee extensors must be corrected. Correction only for the effect of gravity is not sufficient.

The value of the correlation at the non-amputated side is always higher than at the amputated side, which is caused by the difference in mass below the knee, between the mass of the lower leg and the mass of the stump with prosthesis (Table I).

The standard deviations of the 5 repeated passive torque measurements with the QD are rather small. This indicates that the reproducibility of this test, at both the amputated and the non-amputated side, is sufficient. The interindividual variability appears to be substantial. The intercepts and slope coefficients differ considerably between the subjects (Figs. 3 and 4). Therefore it is advised that for each subject an individual GCC is used in isokinetic dynamometry. When the Cybex II Plus dynamometer is used, only a passive torque curve from extension to flexion can be produced and not from flexion to extension because of the design of the dynamometer. In a previous study with healthy subjects we found that measuring from extension to flexion will reduce the passive torque curve by 2 Nm maximally (4). Therefore it is possible to assess a GCC with the Cybex II as well.

In the following situations it is worth while to consider the need for correction:

- when torque of the amputated leg is compared with the torque of the non-amputated leg, because of the difference in mass.
- when small torques are measured, for example in testing below knee amputees, patients with osteoarthrosis or with neuromuscular impairments.
- when torque is measured at the end of the range of motion, i.e. between 0.52 and 0 rad. In this range isokinetic torque rapidly decreases while the effect of gravity increases.
- when the ratio of the knee extensors and flexors torque or the ratio of the knee extensors and flexors mechanical work is determined, because all contractions against gravity are in error on the low side, whereas those acting with gravity are erroneously high (7).

CONCLUSION

Contrary to what was expected on the basis of the mathematical approach, the passive isokinetic torque registration of the knee extensors, is a straight line. In the range of motion not only gravity has a negative effect on the torque produced by the knee extensors, but other factors as well. Therefore it would be better to speak of a "correction curve" instead of a "gravity correction curve". The reproducibility of the passive isokinetic torque registrations is high. Large differences exist between the torque registrations of the individual subjects. Therefore an individual GCC has to be made directly with the dynamometer.

For an ideal torque measurement of the knee extensors, all factors, gravity and biomechanical factors, must be corrected.

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